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Investigation of the contribution of viscoelastic polymer gel pad usage to the accuracy of magnetic resonance elastography measurements: A preliminary study

Polymer gel pad impact on elastography

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Abstract

Aim: The aim of this study was to investigate whether the use of a gel pad contributes to the calculation of stiffness in elastography examination and thus to its diagnostic value by measuring the magnetic resonance elasticity values of relatively curved body parts, such as the knee joint.

Material and Methods: Our study was performed using a data series of 52 knee joint magnetic resonance images obtained from 45 patients were examined. The examinations were performed on elastography images obtained using extra drivers in addition to the standard examination performed with a 3 Tesla magnetic resonance device. Patients who appeared normal with no radiological abnormalities during and after the acquisition of conventional images were included in the study. In the elastographic evaluation performed on the tendon in these normal cases, measurements were taken at different locations of the tendon, with and without a gel pad, and the stiffness values were statistically analyzed.

Results: In examinations with the gel pad, stiffness values were in a more homogeneous range, the standard deviation was lower ±77, and stiffness values from the same location were correlated ($p<0,05$), while in examinations without the gel pad, the standard deviation was larger ±112 and stiffness values were more inconsistent.

Discussion: As a result, it was concluded that the use of gel pads in magnetic resonance elastography, especially for curved body surfaces, contributes to the accuracy of stiffness value measurement and increases the reliability of the evaluation.

Keywords

Active Driver, Elastography, Gel Pad, Magnetic Resonance, Passive Driver, Stiffness

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Introduction

Although the elastography method has only recently begun to gain popularity in daily radiological practice, it is becoming increasingly used. This method, which is based on the measurement of tissue stiffness, was previously used in addition to ultrasonography; however, although the standards have not been fully established, it has gradually become integrated into magnetic resonance imaging (MRI), especially in liver examinations. We believe that the standardization of MR elastography (MR-E) will accelerate with the contribution of studies in the literature.

MR-E examination has started to be seen as a current alternative method in radiology, especially in the liver parenchyma, and there is a need for studies to be integrated into frequently used examinations with a short procedure time to standardize it in general and to make it available for the musculoskeletal system. One of the optimum examinations with these common features is knee joint MRI.

The ability to visualize tendons, ligaments, and soft tissues, in addition to bone, creates the need for MR to be used significantly in musculoskeletal examinations. In particular, knee MRI constitutes an important part of MRI examinations in daily radiology routines.

Compared to most other examinations, knee MRI examinations have well-defined standards, are similar to other extremity MRI examinations, and can be performed without the influence of physiological movements such as respiration, unlike moving anatomical structures such as the abdomen. In addition, because the patellar tendon is anatomically located superficially, measurements made from the patellar tendon over the knee MRI examination were preferred in this study.

Material and Methods

Ethic approval, case selection and study design

The Academic Boards and Ethics Committees of Istanbul Nişantaşı University and BHTCLINIC Istanbul Tema Hospital gave their consent and authorization for our study to be carried out in the radiology division of the BHT Clinic Istanbul Tema Hospital, which is connected to Istanbul Nisantasi University (Approval date 29.06.2022, meeting number 2022/27-3).

This prospective study was conducted in August 2023. During and after MRI, the images were evaluated by two radiologists with more than 10 years of experience in knee MRI using the image archive system. Patients with abnormalities on knee MRI, particularly joint effusion, space-occupying mass lesions, ligaments, and/or tendon abnormalities, were excluded from the study. Thus, 52 knee joint MRI images obtained from 45 patients were included in this study. Six of our cases were female and 39 were male. The ages of our cases were between 21-54 years and bilateral knee joints were examined in 7 patients, and unilateral knee joints were examined in 38 patients. In 3 of the 7 unilateral cases, the right knee was examined in 3 cases and the left knee was examined in 4 cases. All our patients were healthy, and routine blood and biochemical tests were normal.

Patients were identified, and images were taken with a gel pad first and then without a gel pad. In both cases, stiffness measurements were performed separately at three different locations: 1/3 proximal, 1/3 middle, and 1/3 distal portions of the tendon for each examination. This method is also important for comparing measurements obtained from different locations of cases in the same category. As the tendon does not have a homogeneous histological structure throughout its course, the stiffness of different parts is expected to have different values.

Features of devices, technical and image assessment

All MR-E examinations were performed at the BHT Clinic Istanbul Tema Hospital radiology department using a 3 Tesla (T) Signa Architect MRI scanner with commercially available software and hardware (General Electric Healthcare, Waukesha, WI, USA and Resoundant Inc. Rochester, MN, USA) [1, 2].

MRI scans were performed using a standard protocol in the supine position with the knee joint flexed at 10°.

We used standard sequences that included sagittal, axial, and coronal proton density (PD) fat-suppressed (FS) images, and axial fast spin-echo (FSE) T2-weighted (W) FS axial and coronal FSE T1W images. T1W images were obtained with 500/20 (TR/TE), 320×288 acquisition matrix, a 16 cm field of view (FOV), and two excitations. PD FS images were obtained with 2840/42 (TR/TE), a 320×256 acquisition matrix, a 16 cm FOV, and two excitations. T2W images were obtained with 3550/60 (TR/TE), 320×256 acquisition matrix, 16 cm FOV, and two excitations. For all cases, the slice thickness was 3 mm and the interslice gap was 1 mm.

MRI images were also obtained digitally using a picture archiving communication system (PACS), and MRI evaluation was performed using the PACS software.

The subjects were positioned supine, head first, with a body air coil centered at the level of the region of interest (ROI). Mechanical shear waves at 60 Hertz (Hz) were generated using an active driver system located outside the scanning room [2]. A rigid passive driver secured against the muscle was used to transmit mechanical vibrations from the active transducer to the body. The rigid driver is the standard device used in FDA-cleared commercially available implementations of the MRI technology. An experienced MRI technologist performed MRI examinations.

The pressure waves obtained from the passive driver were technically transferred to the active driver and integrated into the images, and elastography images were obtained.

During acquisition, an extra hardware device called a passive driver was inserted into the standard limb coil.

The apparatus we used as a gel pad consists of a material that contains viscoelastic polymer, whose outer coating does not cause harm to the skin (Clearview Healthcare Products Inc. Model no: AP081 South Korea) (Figure 1).

In materials science and continuum mechanics, viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation [3]. Viscous materials, such as water, resist shear flow and strain linearly with time when stress is applied. Elastic materials strain when stretched and immediately return to their original state once the stress is removed. Viscoelastic polymers can create homogenization and magnification effects in the wave by changing the refractive index of the sound and radiofrequency waves by changing their surfaces.

The scans were first performed by placing only the passive driver and then placing a gel pad between the passive driver and the knee joint (Figure 2).

MRI images were processed using commercially available software (MR Touch, GE Healthcare, Waukesha, WI, USA and Resoundant Inc. Rochester, MN, USA) to generate magnitude, phase, and wave maps. Six relative stiffness images were reconstructed for each slice location. The resulting data were measured using ROIs in the muscle on anatomical T1 images and copied onto the MR-E stiffness maps to measure stiffness values (or elastograms) in Pascal (Pa) (Figure 3).

The patellar tendon was divided into three equal parts, and a circular ROI was drawn in the center of each part, not extending beyond the tendon borders. Measurements were made from this ROI (Figure 3, Image C). In the literature, it is known that the sensitivity and specificity of measurements decrease as the ROI area increases in elastography examinations [4,5]. Since the cases included in our study were normal cases and the patellar tendon thicknesses were within the normal value accepted in the population, we found that a 6 mm^2 ROI area was the optimum for measurement during our measurements. The reason for 6 mm2 is that when we selected the ROI area at this value, we obtained both the smallest ROI area and an ROI covering the entire border of the tendon in the measured region. We used a 6 mm2 ROI as a standard in all cases. The measurements were performed separately for each examination without a gel pad (Figure 3 image D) and with a gel pad (Figure 3 images A and B) as described, and stiffness values were recorded separately.

Statistical analysis

Mean age and stiffness values of the patellar tendons were reported as mean ± standard deviation (SD). Levene's test was used to assess the homogeneity of variances based on the mean ± SD values. A parametric analysis of variance (one-way ANOVA) was used to compare each group, including the different ROI of the same tendon on different sides, and Student's t-test was used for binary comparisons of the stiffness values. Stiffness values measured from ROIs at different locations of the same tendon were measured separately with and without the gel pad and statistically analyzed. In addition, stiffness values obtained from mutually symmetrical ROIs of the same bilateral patellar tendon were statistically evaluated in cases of bilateral examinations. Correlations between without gel ped stiffness values and with gel ped stiffness values were studied using Pearson's correlation test (Pearson correlation coefficient = r).

All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) (version 27.0, IBM Corp. , Armonk, N.Y. , USA) and a "p" value of lower than 0.05 was accepted to show statistical significance within a 95% confidence interval (CI).

Ethical Approval

Ethics Committee approval for the study was obtained.

Results

Of the seven patients who underwent bilateral examination, six were female and one was male, and of the 38 patients who underwent unilateral examination, all were male. The mean age of our patients was 34.3 ± 7.2 years. The mean age of our female patients was 29.2 ± 4.1 and the mean age of our male patients was 35.4 ± 1.3.

There was no statistically significant correlation between the age of the patients and the measurements made with and without gel pads (p>0.05) (Table 1).

In the measurements we took without using gel pads, we found the smallest stiffness value of 211 Pa and the largest stiffness value of 1813 Pa in the measurements we made in the ROI areas in all parts of all patellar tendons in all examinations. We calculated the mean stiffness value obtained from this analysis as 713 ±112 Pa. When we performed the same examination and analysis using gel pads, we found that the smallest value was 317 Pa, the highest value was 1217 Pa, and the mean stiffness value was 661 ±77 Pa. The standard deviation of the mean value decreased when gel pads were used (Table 2).

In all knee MRI examinations, patellar tendon measurements from the proximal, middle, and distal parts of the patellar tendons with and without gel pads were evaluated separately. No significant correlation was found in stiffness measurements without gel pads in each ROI (p>0.05). When the stiffnesses measured from the proximal and middle ROIs were compared, p=0.07, p=0.12 and p=0.08 were found between the middle and distal ROIs. However, when the measurements made with the gel pads separately from each ROI level were compared, a significant correlation was observed (p<0.05). When the stiffnesses measured from the proximal and middle ROIs were compared, p=0.04, p=0.02, and p=0.03 were found between the middle and distal, proximal, and distal ROIs, respectively (Table 3).

It was concluded that the use of gel pads contributed to the homogeneity and consistency of the stiffness value measurement in MR-E examination and statistically increased sensitivity, specificity, and reliability.

Table 1. Correlation between age and stiffness values of our patients.

	With gel pad	Without gel pad
Age	p=0.391	p=0.091

p: Pearson's correlation coefficient

Table 2. Stiffness values obtained from ROI areas of all parts of all patellar tendons of all examinations with and without gel pads.

	Stiffness value (Pa)	
	With gel pad	Without gel pad
Min	211	317
Max	1813	1217
Mean ±sd	713 ±112	661 ±77

Max: maximum, Min: minimum, Pa: Pascal, sd: standard deviation

Table 3. Comparison of stiffness values with and without gel pads according to the levels of measurement.

	Prox./Cent.	Cent./Dist.	Prox./Dist.
With gel pad	p=0.04	p= 0.02	p= 0.03
Without gel pad	p=0.07	p=0.12	p= 0.08

Cent.: Central, Dist.: Distal, p: Pearson's correlation coefficient, Prox.:Proximal

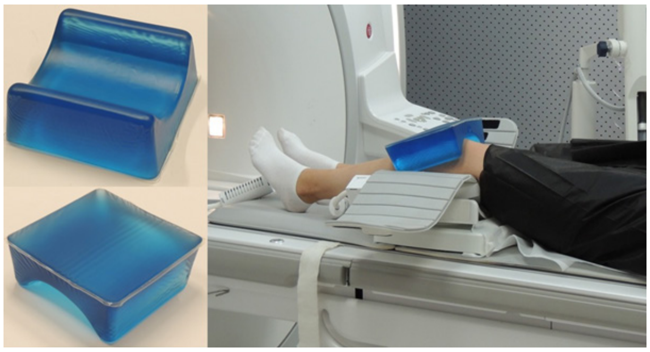

Figure 1. The image on the left shows the concave surface of the gel pad conforming to the knee curve on the top, and the surface contacting the passive divera on the bottom. The image on the right shows the application of a gel pad.

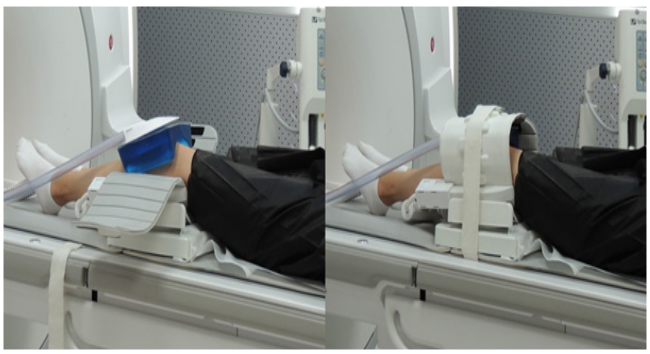

Figure 2. The image on the left shows the placement of the passive driver and the gel pad. The picture on the right shows the passive driver and gel pad inserted into the coil, and the coil in the closed state.

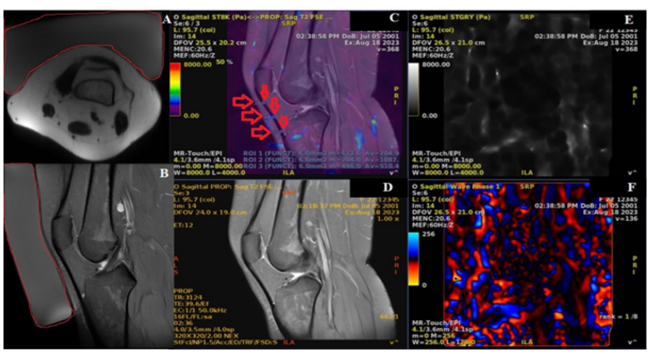

Figure 3. Conventional MRI images are shown on the far left, with the top (A) localizer image and bottom (B) proton density sagittal image showing gel pads in the areas delimited by the red line. The other images were obtained from the workstation where elastographic evaluations were performed. The fusion image at the top center (C) shows the foci of stiffness measurement of the tendon at three different locations of the patellar tendon (horizontal red arrows) within the circular ROIs (vertical red arrows) within the borders of the endon, obtained from the proximal middle and distal parts for each case with and without the gel pad, as seen in the sagittal proton density image at the middle bottom (D). On the far right, the top image (E) shows the wave map of the elastography examination and the bottom image (F) shows the moving pressure color map. These technical measurement applications were performed with and without gel pads for each case.

Discussion

Since MR-E is currently used to obtain data on focal or diffuse liver parenchymal diseases, particularly for the prediction of liver fibrosis, an additional apparatus has been designed to have a surface suitable for the anterior abdominal wall [1, 2]. In these patients, the contact surface of the passive driver with the patient was relatively more planar than the anterior abdominal wall. However, as the data in the literature have been reviewed, it is considered that it can be used radiologically to detect diseases in many tissues and organs [4].

To overcome the technical limitations in the radiological application of MR-E, the primary factors that need to be controlled are the stages of sending radiofrequency pulses to the tissue and receiving the signal from the tissue. It is thought that additional hardware technical apparatus may be useful both to homogenize the medium through which the pulse and signal travel and to increase the transmitted pulse and signal transmission by eliminating the air gap between the coil, which is a standard device, and the passive driver, which is an extra device specific to MR-E [1, 2, 6]. Viscoelastic polymers fulfill this function by eliminating the air gap in ultrasound imaging. MR-E examination is rare today because of the need for extra hardware and software technology in addition to the standard MRI device and apparatus [7]. Thus, every study will contribute to the literature and to the routine functionalization of this advanced imaging examination. The data presented in this study are important. In addition to commercially produced and used passive drivers with a diameter of 19 cm, there is a need for devices with smaller diameters that can be applied more easily to curved body surfaces.

In the literature, elastography examination of tendons has been studied, particularly with ultrasound shear wave elastography (SWE), and there is a heterogeneous scale of data in terms of normal tendon stiffness values [8-12]. In these studies, normal stiffness values were presented in a very wide range of 75–250 kPa. Tendon examination with MR-E was performed by Ito et al. for the detection of pathologies, but there is no satisfactory study in the literature other than this study [13]. Since the physical principles of ultrasound elastography and MR-E are different, comparison of stiffness values obtained from the two techniques is inconsistent.

Location is important for tendon measurements in the study by Arda et al. [9]. This is because the histological structure and stiffness of different parts of the tendons are different. In our study, we paid attention to this and took measurements from different regions, created categorizations according to these regions, and made statistics accordingly. In addition to the different histological structures of the different parts of the tendons, the distance to the bone and its relationship with the bone are also determinative in both ultrasound elastography and MR-E. In our study, more consistent results were obtained in the middle part of the patellar tendon and more contradictory stiffness values were obtained in the proximal and distal parts. Similarly, Aubry et al. found more consistent results in the middle part of the tendon and more heterogeneous values in the distal part close to the calcaneus [10]. Our study aimed to prevent this heterogeneous measurement variation due to the location of the intermediate apparatus and obtain consistent results.

Limitations

The most obvious limitation of this study was the small number of patients. The fact that the medical and personal characteristics of our patients, other than the normality of the basic routine health tests, were not included in the study is also a limitation. Another limitation is the lack of inclusion of variations in the anatomical characteristics of tendons in the analyses.

Conclusion

It was concluded that placing a gel pad between the passive driver and the joint as an intermediate apparatus and performing MR-E in this manner increased the sensitivity, specificity, and reliability of the examination by contributing to the homogeneity and consistency of the stiffness value measurement.

Scientific Responsibility Statement

The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and human rights statement

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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Conflict of interest

The authors declare no conflict of interest.

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